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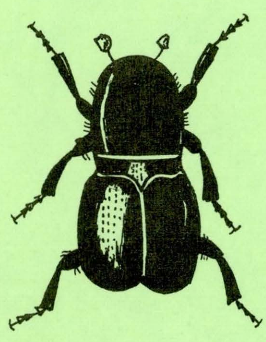
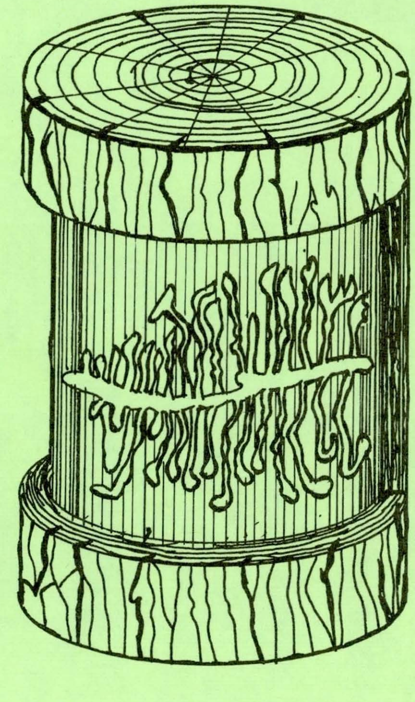
WEATHER, LOGGING, and TREE GROWTH associated with FIR ENGRAVER ATTACK SCARS in WHITE FIR

George T. Ferrell





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THE AUTHOR

GEORGE T. FERRELL, a research entomologist, is studying the biology, ecology, and control of destructive forest insects, with headquarters in Berkeley, Calif. Native of Klamath Falls, Ore., he earned three degrees at the University of California, Berkeley: bachelor's in forestry (1959), master's in zoology (1965), and a doctorate in entomology (1969). Before joining the Station's research staff in 1969, he was a postdoctoral fellow at Simon Fraser University, British Columbia, Canada.

ACKNOWLEDGMENTS

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Bark beetle epidemics in Europe and North America have often been associated with periods of drought, defoliator outbreaks, or stand disturbance, such as logging, windthrow, and ice breakage (Rudinsky 1962). Outbreaks of the fir engraver *(Scolytus ventralis* Lec., Coleoptera: Scolytidae*)*, resulting in severe depletion of stands of true fir *(Abies* spp.*)*, have occurred sporadically in every decade since 1900 in Western North America. Only a few of these epidemics have been studied, however, to determine possible underlying factors, such as drought or host tree defoliation (Stevens 1956; Wickman 1963). Investigations have been hampered by the lack of long-term quantitative estimates of *S. ventralis* populations and the associated fir mortality, as past surveys were largely confined to bark beetles infesting the more commercially valuable tree genera.

Many workers have noted numerous scars, the evidence of past fir engraver attacks, embedded in the stems of living firs (Berryman 1969; Felix, *et al.* 1971; Johnson and Shea 1963; Struble 1957). The beetles bore into the bark and excavate an egg gallery in the cambial zone. If the tree survives the attack, a necrotic lesion is produced which is gradually healed over by the surrounding host tissues. The scar is embedded in the annual ring formed in the year of attack, allowing the attacks to be readily dated. Thus the scars provide a potentially valuable long-term record of past *S. ventralis* activity.

This paper relates temporal fluctuation in abundance of the attack scars in white fir *(Abies concolor* [Gord. & Glend.] Lindl.*)* to trends in host tree growth mortality, weather, and logging operations for the period 1934–69, using multiple regression analysis.

STUDY AREAS

Attack-Scar Plots

Boles of white fir were sampled in 1970 for *S. ventralis* attack scars within two plots on the west slope of Mount Lassen, Shasta County, California. The plots were about 4 miles apart in cutover mixed conifer forest. White fir grew in association with Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco*)*, ponderosa pine *(Pinus ponderosa* Laws.*)*, sugar pine *(Pinus lambertiana* Dougl.*)*, incense cedar *(Libocedrus decurrens* Torr.*)*, and California black oak *(Quercus kelloggii* Newb.*)* in uneven-aged stands. The two plots differed in the proportion of the mature stand removed by past logging operations and in the level of current fir mortality caused by *S. ventralis.* The first cycle of logging on both plots, 1949-57, removed about 50 percent of the timber volume. Portions of both plots were logged again in 1958-70.

The Dersch Meadow plot (2,440 acres at 4,000 ft. elevation) had been heavily logged; only 3 percent of the original volume of mature timber remained in 1970 after the second cycle of logging. The residual stand consisted of scattered clumps of formerly intermediate or suppressed trees interspersed with openings in which shrubs and forbs predominated. Firs recently killed or under current attack by *S. ventralis* were scattered throughout the stand.

The Beal's Place plot (1,280 acres at 4,500 ft. elevation) had not received a second cutting until summer of 1970, the year of this study. Up to that time, the forest cover was more nearly complete than at Dersch Meadow; large (dominant) trees were still present. No firs recently killed by *S. ventralis* were observed in 1970 on this plot.

Fir-Mortality Plots

White fir mortality caused by *S. ventralis* during the period 1939-54 was surveyed on 15 tree-mortality plots (each 20 acres) established within a radius of 30 miles to the northeast of the plots at Dersch Meadow and Beal's Place by entomologists of the Pacific Southwest Forest and Range Experiment Station (Hall 1958). The mortality plots sampled mixed conifer stands varying in logging history (virgin to

completely cutover), elevation (4,700 to 6,200 feet), and proportion of white fir. The plots represented a reasonable cross section of stands containing white fir in the region.

Fir engraver populations, as expressed by fir mortality, fluctuated synchronously over the entire region embracing the attack scar and fir mortality plots, at least during certain years within the study period. Forest insect surveys for the region reported that fir engraver damage was generally high in 1939-40 and low in 1948.[1] Thus it seemed likely that trends in fir mortality on the mortality and attack-scar plots would be similar.

In the absence of sound bark beetle population estimates, tree mortality has been commonly used in the past as an index to bark beetle population levels. The present study includes comparison of yearly trends in white fir mortality with those in the abundance of the yearly attack scars to determine whether the scars are a reasonable index to population trends.

SAMPLING AND DATA COLLECTION

Attack Scars

Dersch Meadow—Thirty-two white firs killed by *S. ventralis* in 1969 were selected for their convenient proximity to roads. The trees were felled and tree height and stump diameter were measured. Each tree was cut into 16-foot logs to a minimum diameter of about 4 inches (upper logs were often less than 16 feet long). A 1-inch-thick cross section (disk) was sawn from the lower end of each log, resulting in from three to five sample disks from each tree.

Beal's Place—The sampling procedure was similar to that of Dersch Meadow except that the 41 sample trees had been selected by foresters for felling as being "high-risk" trees likely to succumb to *S. ventralis* attack and were living when felled; also, the butt log was 32 feet in length. A summary of the diameter, height, and age of the sample trees from each plot indicates that Beal's Place trees tended to be larger and older than those from Dersch Meadow *(table 1)*, where most of the large old firs had been removed by past logging.

Table 1—*Diameter, height, and age of white firs sampled for embedded S. ventralis attack scars at two locations, Shasta County, California, 1970*

Items	Dersch Meadow (32 trees)		Beal's Place (41 trees)	
	Mean	Range	Mean	Range
Diameter at stump . . . in.	15.0±2.9	10–20	22.4±4.4	13–35
Height . . . . ft.	63.1±10.8	43.5–85.8	74.5±18.6	41.2–110.2
Age at stump . . . . yr.	99.5±21.4	61–151	125.5±32.9	85–239

One surface of each disk was sanded with both coarse- and fine-grit papers. *S. ventralis* attack scars were visible in cross section as dark-stained segments of the annual rings *(fig. 1)*. A band saw was used to make radial cuts from the disk exterior to each scar, and the resulting wedge was split out with hammer and chisel to expose the scar. Viewed tangentially, the scars varied from small round niches to elongated egg galleries oriented normal to the wood fibers; surrounding host tissues were impregnated with a dark brown resinous stain *(fig. 2)*.

The year of attack was estimated by subtracting the number of annual rings formed in years subsequent to the attack from the year when the outer annual ring was formed. Also, each scar was examined for the presence or absence of larval mines and pupal chambers as an indication of the reproductive success or failure of the attack.

Tree Growth

Four radial sections, approximately 1/2 inch in width and oriented normally to one another, were cut from each tree's basal disk with a band saw. The presence of decay in some disks made only one to three sections obtainable. The sections were oven-dried (110°C., 6 hr.) to stabilize future shrinkage, and the width of all annual growth rings was measured to 0.01 mm.

[1] Salman, K. A. *Reconnaissance of west side infestation conditions. Season of 1939.* 8 p. 1939. Engen, E. T. *Forest insect survey. Lassen National Forest and adjacent private lands. Seasons of 1949 and 1950.* 24 p. 1950. (Unpublished reports on file at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California.)

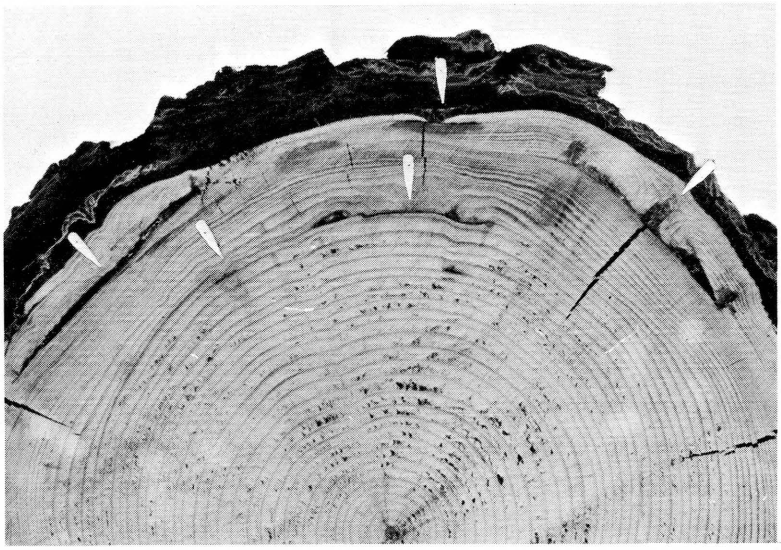

Figure 1—In transverse view, *S. ventralis* attack scars embedded in the annual rings of white fir are visible as dark-stained ring segments (arrows).

Tree Mortality

Yearly tree mortality on the fifteen, 20-acre plots was surveyed from 1939 through 1954 by annual examination of all trees on each plot in late fall or early spring, after trees killed by subcortical insects the preceding summer showed faded foliage (Hall 1958). The species, diameter at breast height (d.b.h.), and height of each faded tree were recorded and the bark was chopped into at breast height to determine the causal insect. Sampling at breast height probably produced a conservative estimate of *Scolytus*-caused mortality; this beetle often kills the upper bole and the lower bole is attacked by the cerambycid, *Tetropium abietis* Fall (Struble 1957). The volume of wood contained in each dead tree was estimated using local volume tables.

Logging

Logging chronologies were constructed for the attack-scar plots from records of the year and approximate boundaries of all known logging operations within the plots and the approximate area of each logged parcel was estimated by superimposing a 40-acre grid, drawn to scale, upon a map.

Weather

Monthly total precipitation (inches) and mean temperature (degrees F.) were obtained from annual summaries of California weather issued by the U.S. Environmental Data Service for the period 1934-69. Shingletown, the weather station nearest the attack-

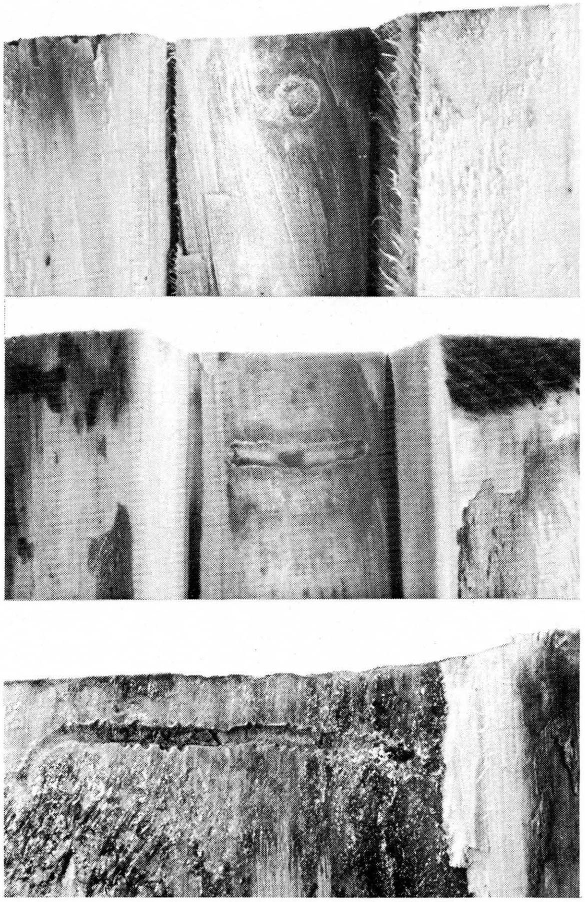

Figure 2—In tangential view, dissected *S. ventralis* attack scars vary in extent of gallery formation from round pockmarks (**top**) to elongated egg galleries oriented perpendicular to the wood fibers (**middle** and **bottom**). Surrounding host tissues are impregnated with a dark brown, resinous stain.

scar plots, did not record temperature data during the study period, and precipitation data from this station were available only after 1960. Weather data from three other nearby stations (Manzanita Lake, Volta, Mineral) were used to fill these gaps. High correlations of data between the stations (r varied from 0.82 to 0.96) indicated that the weather patterns of the stations were similar. Thus, precipitation records from all four stations, and temperature records from three stations, were used in the regression analysis.

ANALYSIS

Multiple regression analysis was used to relate yearly number of *S. ventralis* attack scars (dependent variable) to weather, growth, logging, and previous abundance of attack scars (independent variables). A linear additive model was used: that is, it was assumed that the relations between the dependent and independent variables were linear and the effects of the latter upon the dependent variable were additive. Because insect populations grow exponentially over time, fluctuations may be large, resulting in a nonlinear relation with other variables. Nonlinearity was at least partially allowed for by introducing the dependent variable as logarithms and including both the independent variables and their squares in the regression.

Regression coefficients and associated statistics were computed by RAFL, a program written by personnel of the Pacific Southwest Forest and Range Experiment Station. The program included a stepping option, by which the variables could be included in the regression model in descending order of their efficiency in explaining attack scar variance (t^2 criterion). Accepted models contained all variables included prior to, and including, the last variable significantly reducing the unexplained variance in attack scars (t^2 probability $\leqslant .05$).

Typically, in such a ranking process, the addition of the most important variable among a group of highly associated variables leaves little variance in the dependent variable to be accounted for by the remaining variables in the complex, resulting in their exclusion from the model even though they are, in themselves, significant. Frequently, no single variable in the complex is able, by itself, to explain a significant amount of the variance, so that the entire complex is excluded, although as a whole it may be significant.

To circumvent these difficulties, an approach (Hardwick and Lefkovitch 1971) has been used which compares the results obtained from two methods of analysis:

Group Analysis: The variables were combined into four major descriptive groupings: weather, growth, previous *Scolytus* attack scars, and logging. The contribution of each group of variables as a whole, singly, and in combination with each of the other groups, to the explanation of attack variance was examined.

Separate Variable Analysis: The variables were introduced into the regression individually, in descending order of the amount by which they reduced the residual attack scar variance.

Dependent Variable: Attack Scars

For each plot, the yearly number of attack scars observed in all sample trees (1934-69) was obtained by summing over all disks. The yearly numbers of attack scars for the two plots were combined and compared with the annual total volume of white fir timber killed by *S. ventralis* on all mortality plots. The two variables were directly correlated, indicating that scar abundance is a reliable index to past levels of fir mortality from *S. ventralis*. Thus the natural logarithm of the total number of attack scars observed on each plot in the ith year, that is, $\log_e$ Attacks_i, i = 1934 through 1969, was used as the dependent variable (Y) in the regression. The value of 1 was added to each year's attacks so that a definite logarithm could be obtained for years with no observed attacks.

Independent Variables

Many workers have stressed the importance of previous as well as current, environmental conditions upon population fluctuations of insects. Therefore independent variables expressing conditions of years preceding the current (ith) year, as well as those of the year itself, were included in the regression.

Weather—The study plots lie in a region whose climate consists of a distinct wet season (usually October to June). The summers are normally warm and dry with precipitation limited to occasional thundershowers. Sums of monthly total precipitation,

and averages of monthly mean temperature, from the previous October through the ith year's September, were considered to represent both the direct and indirect (via host tree) influences of weather upon the beetle population during the ith year ($Precip._i$, $Temp._i$). The year's weather was subdivided by seasons (Win. $Precip._i$, $Temp._i$, October-March; Spr. $Precip._i$, $Temp._i$, April-June; Sum. $Precip._i$, $Temp._i$, July-September) to assess the influences of each, as different developmental stages of the insect occur seasonally. The immature (brood) stages of *S. ventralis* are present subcortically during fall, winter, and spring, whereas emergence, flight, and attack of the adults occur during the summer. Weather during years preceding the ith year was taken into account by averaging precipitation in the ith year with that of up to 4 preceding years ($Precip._{i,j}$, j=1-4).

Growth—Measurements of the radial increment (stump level) of the trees were used to indicate variable host vigor. Tree growth expresses the combined influence of many factors—weather, disease, plant competition, fire, defoliation by insects, etc.—and is thus an indirect measure of many factors for which records were lacking.

The several measurements of the width of each growth-ring, obtained from the sticks from each tree's basal disk, were averaged to obtain the mean width for each ring formed during 1934-70. A yearly mean growth index was calculated from data from each plot by means of the computer program INDXA[2] written by Fritts, *et al.* (1966). The ith year's mean growth index for all sample trees from each plot ($Growth_i$) and averages of the ith year's growth with that of up to 3 previous years ($Growth_{i,j}$, j=1 to 3) were included in the regression.

Logging—Several possible influences of logging activity on *S. ventralis* populations were assessed. Cum. Log_i was the cumulative area logged within each plot (in hundreds of acres) since the beginning of logging operations on that plot through the ith year. It attempted to represent the long-term cumulative effects of stand disturbance by successive logging operations (i.e., increased tree moisture stress resulting from opening the stand, disturbance of root system by logging equipment, entrance to decay organisms through wounds and stumps). The area logged within the plot in the previous year (Log_{i-1}) was considered to be primarily an index to the abundance of recent logging slash as suitable breeding sites as *S. ventralis* readily attacks and reproduces in such host material (Stevens 1956; Struble 1957). However, this variable also expressed stand disturbance caused by logging in the previous year.

Attack Scars in the Preceding Year—As an index of *S. ventralis* abundance, the total number of attack scars observed in all trees from each plot for the preceding year ($Attack_{i-1}$) was included in the regression. Population trends seem to be less predictable for bark beetles than for many other groups of forest insects. For many species of scolytids, however, increased populations (in excess of endemic levels) have often preceded outbreaks (Rudinsky 1962). Like the dependent variable $Attacks_{i-1}$ was transformed to logarithmic scale.

RESULTS AND DISCUSSION

A total of 188 embedded scars in annual rings corresponding to the years 1934-68 was found in the Dersch Meadow trees. An additional 363 attacks were found on the surface of the outer ring—attacks resulting from the mass invasion which killed the trees in 1969. All of the 1969 attacks, but only 3.2 percent of the embedded scars, represented attacks that were reproductively successful. Only 2 percent of the 99 attack scars embedded in Beal's Place trees for the period 1934-69 gave evidence of reproductive success.

The yearly total scars in all trees from both attack-scar plots (pooled) was directly correlated (r=0.72) with the annual volume of white fir killed by *S. ventralis* on the mortality plots between 1939 and 1954. Similarity in the yearly trends of the two variables was evident *(fig. 3)*.

[2]This program fits a negative exponential curve or a straight line with zero, positive, or negative slope to each tree's ring width series by the least squares method, selecting the function which provides the best fit. A growth index is calculated for each year by dividing the observed ring width by the curve value. Growth indexes of unity represent normal, 0-1 subnormal, and greater than one, above normal, growth. Summaries including all trees from a given plot are then computed, yielding yearly mean growth indexes and associated statistics (standard deviation, standard error) for each plot. The curve-fitting and index calculations attempt to eliminate long-term systematic growth patterns such as those associated with tree age, and to isolate for analysis year-to-year fluctuations in growth caused by environmental variables such as weather.

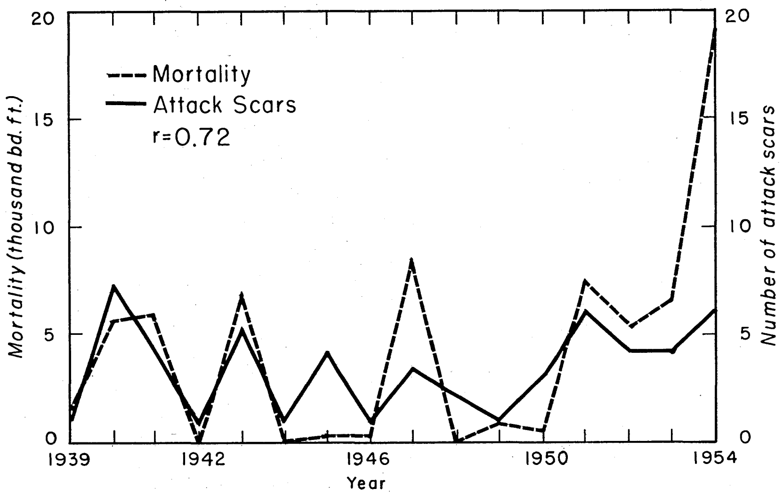

Figure 3—Fluctuation of the yearly total of *S. ventralis* attack scars (73 trees from two plots) was generally synchronous with the annual volume of white fir killed by *S. ventralis* (fifteen 20 acre mortality plots), 1939-54.

Factors Related to Attack Scars

Grouped Factors—The groups of variables representing logging activity and weather were most important in explaining attack scar variance on both plots *(table 2)*. In combination they explained 93.7 and 79.9 percent of the attack scar variance at Dersch Meadow and Beal's Place, respectively. Host tree growth explained an additional 4 percent at Dersch Meadow and 11.5 percent at Beal's Place when added to the model already containing logging and weather. Although scar abundance in the previous year ($Attacks_{i-1}$) by itself explained 57.3 percent and 12.1 percent of the scar variance on the two plots, its addition to the model already containing logging increased the amount of explained variation by only 0.5 and 1.6 percent, respectively. Evidently there was a great deal of overlap in the influence of the previous year's levels of logging and attack scars upon the dependent-variable with logging able to explain a greater amount of the variation.

Separate Factors—Logging was the most important single variable on both plots *(table 3)*. The next most significant variables were current tree growth (Dersch Meadow) and certain precipitation variables on both plots.

The importance of logging and weather in the years preceding the ith year differed between the plots. Variables representing ith year's precipitation and the previous year's logging were more important at Beal's Place, whereas only variables combining ith year conditions with those of at least several previous years were important at Dersch Meadow.

On both plots, precipitation during the entire season (October through September) was more significant than either winter or spring precipitation alone. Mean temperatures had relatively little influence compared to precipitation.

As in the group analysis, the previous year's beetle activity ($Attacks_{i-1}$) did not make a significant contribution in either plot once logging variables had been taken into account.

Table 2—*The contribution of grouped factors, singly and in combination, to the explanation of S. ventralis attack scar variation on two plots, Shasta County, California, 1934-69*

Factor grouping	Cumulative percentage of variation explained ($100R^2$)
Dersch Meadow	
Logging	72.3
Weather	71.0
$Attacks_{i-1}$ [1]	57.3
Growth	40.1
Logging + Weather	93.7
Logging + Growth	78.8
Logging + $Attacks_{i-1}$	72.8
Logging + Weather + Growth	97.7
Logging + Weather + Growth + $Attacks_{i-1}$	97.8
Beal's Place	
Weather	56.9
Logging	35.2
Growth	12.8
$Attacks_{i-1}$	12.1
Logging + Weather	79.9
Logging + Growth	42.6
Logging + $Attacks_{i-1}$	36.8
Logging + Weather + Growth	91.4
Logging + Weather + Growth + $Attacks_{i-1}$	98.0

[1] Number of attack scars in the previous (i-1) year.

Table 3—*The contribution of single factors to the explanation of S. ventralis attack scar variation on two plots, Shasta County, California, 1934-69*

Factors, ranked in descending order of efficiency in explaining scar variation[1]	Cumulative percentage of variation explained ($100R^2$)
Dersch Meadow	
Cum. $Log._i{}^2$ - Cumulative area logged, squared	71.4
$+Growth_i$ - Mean growth index for current year	77.7
$+Precip._{i,2}$ - Mean precipitation for current and two preceding years	79.5
$+Precip._{i,1}{}^2$ - Mean precipitation for current and preceding year, squared	85.6*
Beal's Place	
$Log._{i-1}$ - Area logged in previous year	13.3
$+Log._{i-1}{}^2$ - Area logged in previous year, squared	34.6
$+Precip._i$ - Precipitation for current year	38.6
$+Precip._i{}^2$ - Precipitation for current year, squared	50.9
$+Temp._i$ - Mean temperature for current year	55.3
+Spr. $Precip._i{}^2$ - Spring precipitation for current year, squared	59.3
+Win. $Precip._i{}^2$ - Winter precipitation for current year squared	68.0*

t^2 significant at 5 percent level, for all factors listed.
*Significant at 1 percent level (F test).

Of the factors investigated, the first four in the ranking explained 85.6 percent of scar variance at Dersch Meadow. The first five factors (including two variables and their squares) explained 68.0 percent of the scar variation at Beal's Place. The amount or scar variation explained by each model was significant by F test at the 1 percent level.

The results suggest that logging, precipitation, and to a lesser extent tree growth, are important factors influencing year-to-year variation in abundance of fir engraver attack scars. Yearly trends in those factors and the scars are depicted for the plots in *figures 4 and 5* with annual precipitation expressed as the departure from average (44.82 inches) during the study period.

The temporal pattern of the attack scars in the Dersch Meadow trees differed from that at Beal's Place. At Dersch Meadow the scars remained low until 1956, but generally increased each year thereafter until the trees were killed by the beetles in 1969. This increase was related to the incidence of repeated logging operations within the plot in an apparently additive manner (Cum. Log.). The period of greatest increase in the scars (1960-69) coincided with generally subnormal precipitation, continued logging, and in the last years before the trees were killed (1956-69), rapidly declining tree growth. It is possible that the accelerating accumulation of the scars during the period 1965-68 may have in itself contributed to the rapid decline in growth and the death of these trees through interference with the functioning of stem tissues. At Beal's Place, three periods of increased attack scars (1940-43, 1950-53, 1961-65), each followed by return to lower levels, were discernible. The latter two peaks were contemporaneous with periods of logging activity. For all three peaks, the year of initial increase in the scars was preceded by at least 1 year of subnormal precipitation and coincided with years of subnormal or declining growth. Precipitation remained generally subnormal throughout the years when the highest peak occurred (1961-65).

The decline of the attack scars during the interludes between logging operations at Beal's Place suggests that the primary influence of logging on this plot was the temporary provision of logging slash as suitable breeding material for the beetles. Continued increase in scar abundance between logging opera-

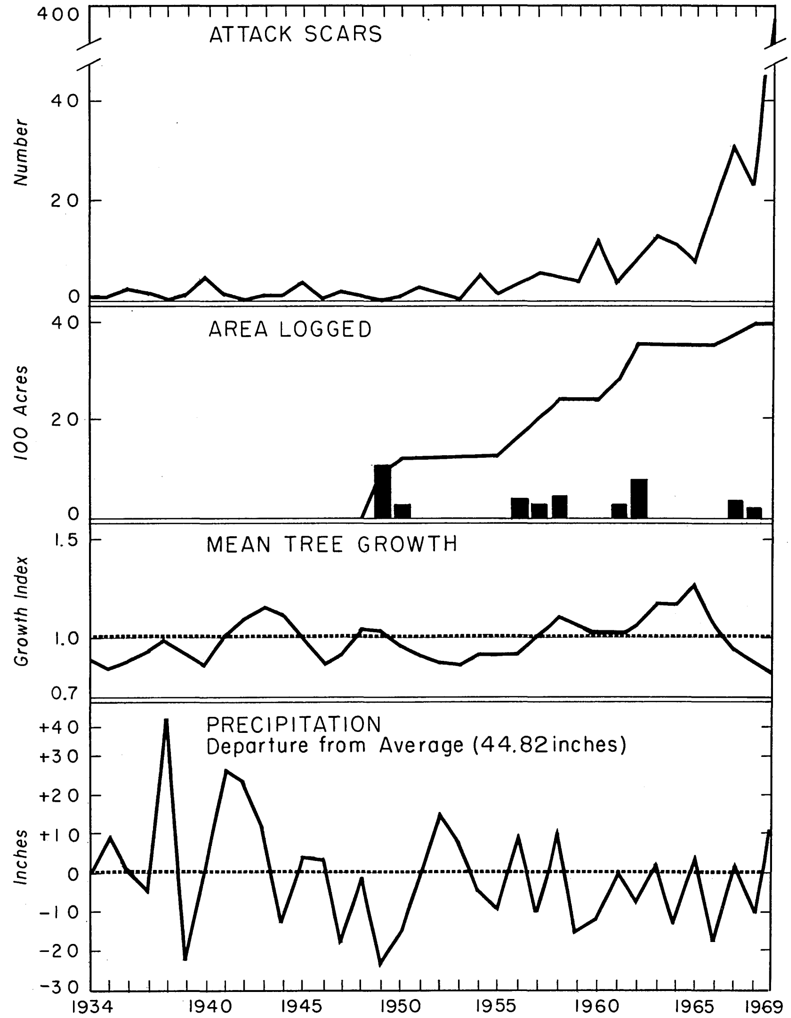

Figure 4--Comparison of trends in factors influencing fluctuation of *S. ventralis* attack scars, 1934-69, Dersch Meadow plot. Both yearly (bars) and cumulative (line) area logged within plot are shown.

tions at Dersch Meadow suggests a longer term influence possibly related to the greater frequency and extent of logging operations on this plot. Logging took place during 9 years at Dersch Meadow, resulting in the removal of 97 percent of the sawtimber volume, compared to Beal's Place, where 5 years' logging removed 50 percent of the volume.

Index to Past Trends

The study results appear to validate the use of attack scars embedded in *Scolytus*-killed and high-risk fir as an index to past trends in fir mortality from *S. ventralis,* even though most of the scars record attacks that were reproductively unsuccessful. Increases in both scar abundance and fir mortality are usually preceded by 1 or more years of subnormal precipitation and coincide with periods of reduced tree growth agreeing with the findings of other investigators. Wickman (1963) found in California that subnormal precipitation preceded outbreaks of tussock moth *(Hemerocampa pseudotsugata* McD.*)* which caused defoliation and reduced growth of white fir. Many of the fir thus weakened were subsequently killed by *S. ventralis.* There was increased incidence of *S. ventralis* attack scars in the tops of white fir infested by true mistletoe, especially following drought (Felix, *et al.* 1971). At Dersch Meadow and Beal's Place, the short- and long-term effects of logging appeared to interact with the effects of drought and subnormal tree growth in a manner similar to that described for outbreaks of *Ips typographus* L. in the spruce forests of Germany (Thalenhorst 1958). Populations of this bark beetle are normally confined (latent phase) to a few fallen trees and dying branches, the scarcity of which acts as the limiting factor. A sudden surplus of nonresistant host material such as logging slash may lead to population increases (extensive phase). The high population produced may then attack living trees (intensive phase), leading to increased tree mor-

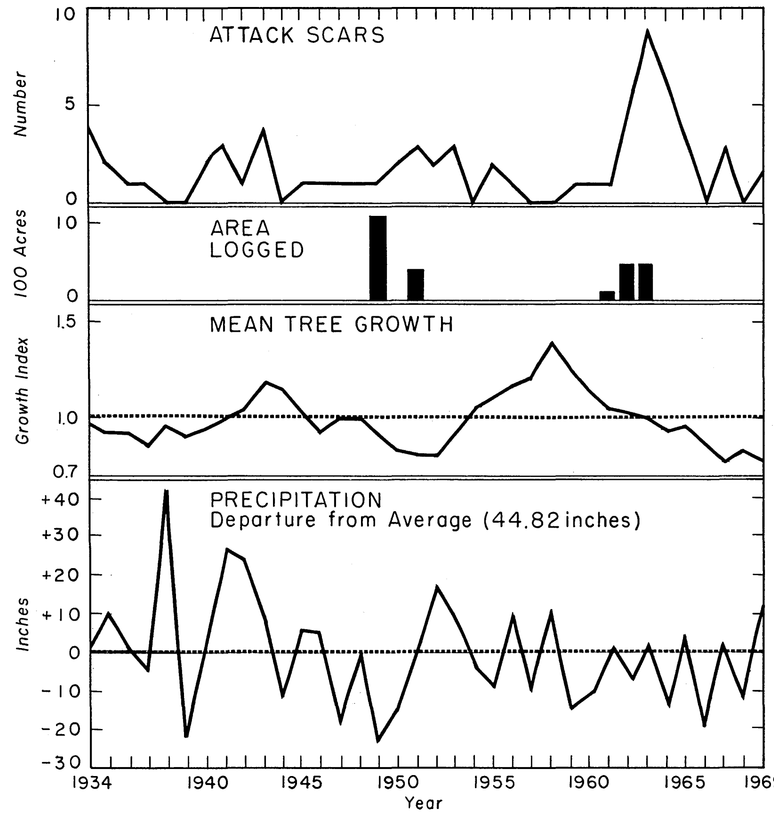

Figure 5—Comparison of trends in factors influencing fluctuation of *S. ventralis* attack scars, 1934-69, Beal's Place plot.

tality. This phase may be prolonged by reduced host vigor resulting from drought. Similar mechanisms have been found in North American bark beetles (Hall 1958). Apparently, scar abundance in any year is:(1) directly related to the abundance of attacking beetles as influenced by the availability of nonresistant host material in the preceding years, and (2) inversely related to host resistance as influenced by drought. The paucity of scars in wetter years probably results from many attacks failing to penetrate the cambium and thus failing to form scars recorded in the annual rings. Such attacks, associated with a rapid, resinous response of the phloem, have been reported in fir successfully resisting fir engraver colonization by Berryman (1969) and Struble (1957).

It seems likely that beetle-caused fir mortality in the residual stand following logging could be reduced if logging of stands containing white fir were deferred until periods of drought and subnormal tree growth are ended. Although the data are not yet conclusive, the study results also suggest avoidance of silvicultural systems calling for repeated logging with removal of a high percentage of the mature stand, leaving only the formerly suppressed and intermediate fir. Thorough slash disposal is also indicated.

The investigation gives direction to future studies of the relation between fir silvicultural systems and the fir engraver. It would appear feasible to develop mathematical models for predicting the amount of fir damage by *S. ventralis* if current and previous levels of logging, precipitation, and tree growth are known. The impact of the estimated mortality levels under alternative managerial schemes could then be assessed, and the forest manager could choose the scheme best suited to his needs.

SUMMARY

Ferrell, George T.

1973. **Weather, logging, and tree growth associated with fir engraver attack scars in white fir.** Berkeley, Calif., Pacific Southwest Forest and Range Exp. Stn. 11 p., illus. (USDA Forest Serv. Res. Paper PSW-92)

Oxford: 453–145.7x91.92: 174.7 *Abies* spp. (794): 461[111.781. + 181.65].
Retrieval Terms: Scolytus ventralis; Abies spp.; mortality; drought effects; logging effects; growth vigor; timber management; Shasta County, California.

Attack scars of the fir engraver *(Scolytus ventralis)* were examined in 73 white fir boles from two plots in Shasta County, California, to determine their usefulness in estimating fluctuation of beetle populations, and to explore their relation to trends in weather and other factors. Of these fir, 32 had been killed by *S. ventralis* and 41 were considered "high risk." The two plots differed in the extent of past logging and in the level of mortality from the beetle. A total of 287 scars formed in 1934-69 were found, from 2 to 3 percent showing reproductive success. Attack scars were dated by a count of annual rings, and yearly totals for the two plots were obtained.

Fir mortality over the period 1939-54 was determined from survey of 15 plots in the vicinity of the attack scar plots.

Scar abundance was examined in relation to both previous and current weather, host tree growth, and logging by multiple regression analysis.

Trends in scar abundance were directly correlated with trends in white fir timber volume killed by *S. ventralis* on the mortality plots, indicating the scars were a suitable index to past damage levels. In the regression analysis, accepted models containing logging, precipitation, and tree growth variables explained 85.6 and 68 percent of the attack scar variation on the two plots. Years with increased scar abundance were preceded by at least 1 year of subnormal precipitation and coincided with subnormal or declining tree growth. The highest peaks in scar abundance occurred when these conditions were contemporaneous with logging in the stand.

Differences in logging between the two plots appeared to influence both trends in the scars and levels of fir mortality caused by the beetles. Study results, although not conclusive, suggest that logging of stands containing white fir should avoid removal of all mature trees leaving only formerly suppressed and intermediate fir. Slash disposal should be thorough. If possible, logging should be deferred until periods of severe drought are ended.

LITERATURE CITED

Berryman, Alan A.
1969. **Responses of *Abies grandis* to attack by *Scolytus ventralis* (Coleoptera: Scolytidae).** Can. Entomol. 101: 1033-1041.

Felix, Leonard S., B. Uhrenholdt, and J. R. Parmeter, Jr.
1971. **Association of *Scolytus ventralis* (Coleoptera: Scolytidae) and *Phoradendron bolleanum* subspecies *pauciflorum* on *Abies concolor*.** Can. Entomol. 103: 1697-1703.

Fritts, Harold C.
1966. **Growth rings of trees: their correlation with climate.** Sci. 154: 973-979.

Hall, Ralph C.
1958. **Environmental factors associated with outbreaks by the western pine beetle and the California five-spined engraver in California.** Proc. Tenth Int. Congr. Entomol. Vol. 4, 1956: 341-347.

Hardwick, D. F., and C. P. Lefkovitch.
1971. **Physical and biotic factors affecting *Euoxa* species abundance in Western North America: a regression analysis.** Can. Entomol. 103: 1217-1235.

Johnson, Norman E., and K.R. Shea
1963. **White fir defects associated with attacks by the fir engraver.** Weyerhaeuser Forest Res. Note 54. 8 p.

Rudinsky, Julius A.
1962. **The ecology of the scolytidae.** Annu. Rev. Entomol. 7: 327-348.

Stevens, Robert E.
1956. **Fir engraver beetle.** U.S. Dep. Agric., Forest Pest Leafl. 13. 7 p.

Struble, George R.
1957. **The fir engraver.** U.S. Dep. Agric., Prod. Res. Rep. 11. 8 p.

Thalenhorst, W.
1958. **Grundzuge der Populationdynamik des grossen Fichtenborkenkafers** ***Ips typographus*** **L.** Schriftenreihe der forstl., Fak. der Univ. Gottingen, 21. 126 p.

Wickman, Boyd E.
1963. **Mortality and growth reduction of white fir following defoliation by the Douglas-fir tussock moth.** U.S. Forest Serv. Res. Paper PSW-7. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 15 p., illus.

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Ferrell, George T.

1973. **Weather, logging, and tree growth associated with fir engraver attack scars in white fir.** Berkeley, Calif. Pacific Southwest Forest and Range Exp. Stn., 11 p., illus. (USDA Forest Serv. Res. Paper PSW-92)

The boles of 32 recently killed, and 41 living, white fir were examined for embedded fir engraver *(Scolytus ventralis)* attack scars. Of 287 scars found in annual rings for the years 1934-69, only 2 to 3 percent represented reproductively successful attacks. Trends in scar abundance were directly correlated with trends in white fir killed by *S. ventralis* on 15 plots from 1939 to 1954. Influence of weather, host tree growth, and logging on yearly abundance of scars was examined by multivariate regression analysis. Years with increased scar abundance were preceded by at least 1 year of subnormal precipitation and coincided with subnormal tree growth. High peaks occurred when these conditions were contemporaneous with logging in the stand.

Oxford: 453–145.7x91.92: 174.7 *Abies* spp. (794): 461[111.781. + 181.65].

Retrieval Terms: Scolytus ventralis; Abies spp.; mortality; drought effects; logging effects; growth vigor; timber management; Shasta County, California.

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